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Note

Stoichiometry of the complexes of methyl glycofuranosides with metal ions in aqueous solution

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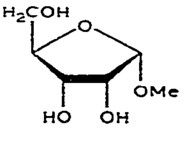
Complexing of metal ions with carbohydrates and their derivatives in neutral, aqueous solution has received considerable interest recently[1,2] because of the possible importance of this kind of interaction in a variety of biological processes, including, for example, the binding of cations to cell walls[3]. Application of ^{1}H-n.m.r. techniques has given valuable information about the preferential binding-sites in polyols and monosaccharides[4-9], whereas data on the stoichiometry of the complexes and the thermodynamics of their formation are scanty[10-14], particularly for complexing with carbohydrates having five-membered rings. Calorimetry of complex formation between methyl glycofuranosides and calcium ions in aqueous solution indicated[14] 1:1 stoichiometry and confirmed earlier suggestions[13] of the relative complexing-abilities of various glycofuranosides. We now report on an extension of the calorimetric investigations to other metal ions having a noble-gas electronic structure. For reference, copper(II) was examined as a typical transition-metal ion and lead(II) as an example of heavy metal ions. Methyl α-D-ribo- (**1**), β-D-ribo- (**2**), and α-D-lyxo-furanosides (**3**), observed to be the most efficient complexing-agents, were chosen as ligands. It should be noted that, with each ligand, the site of complexing is probably different: namely, MeO-1, HO-2, and HO-3 for **1**; HO-2, HO-3, and possibly the ring oxygen for **2**; and HO-2, HO-3, and HO-5 for **3**.



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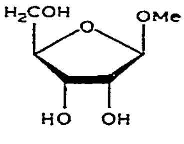

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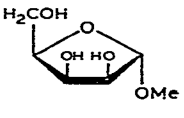

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Table I records the enthalpies of interaction [ΔH(int.)] of various metal ions with the methyl glycosides **1**–**3**. Application of Job's method of continuous variation[15] to the data reveals that the complexes of each ligand with the alkaline-earth metal cations are of the 1:1 type (Fig. 1a), in accord with previous observations[14] for Ca^{2+}.

TABLE I

ENTHALPIES OF INTERACTION [ΔH(int.)] OF METHYL α-D-ribo-, β-D-ribo-, AND α-D-lyxo-FURANOSIDES WITH VARIOUS INORGANIC SALTS IN AQUEOUS SOLUTION AT 298.2 K

MX_z	[M^{z+}]	[L]	$-\Delta$H(*int.*) (*mJ*)[a]		
	(*mol.dm^{-3}*)	(*mol.dm^{-3}*)	*α-Riboside*	*β-Riboside*	*α-Lyxoside*
$MgCl_2$	0.1	0.3	30		10
	0.2	0.2	30	20	20
	0.3	0.1	4		1
$CaCl_2$[b]	0.1	0.3	270	50	100
	0.2	0.2	370	80	180
	0.3	0.1	280	50	110
$Ca(NO_3)_2$	0.1	0.3	300	80	130
	0.2	0.2	420	130	190
	0.3	0.1	320	80	140
$SrCl_2$	0.1	0.3	230		60
	0.2	0.2	260	50	100
	0.3	0.1	210		80
$BaCl_2$	0.1	0.3	260		40
	0.2	0.2	350	60	80
	0.3	0.1	280		50
$Y(NO_3)_3$	0.1	0.3	40	60	50
	0.2	0.2	40	80	80
	0.3	0.1	20	40	40
$La(NO_3)_3$	0.1	0.3	110	100	150
	0.2	0.2	110[b]	110	230[b]
	0.3	0.1	100	80	170
$Cu(NO_3)_2$	0.1	0.3	30	30	20
	0.2	0.2	20	50	40
	0.3	0.1	10	30	20
$Pb(NO_3)_2$	0.1	0.3	380	70	100
	0.133	0.267	400	80	120
	0.2	0.2	380	70	90
	0.3	0.1	200	2	30

[a] The enthalpy of mixing of 1.75 cm^3 of the solutions given, corrected with respect to the enthalpies of dilution. [b] Taken from ref. 14.

In Fig. 1b, the same method has been applied to the enthalpies of interaction obtained with trivalent cations of yttrium and lanthanum, having the electronic structure of a noble gas, analogous to the cations of alkaline-earth metals. In contrast, a similar treatment of the data for Pb^{2+} suggests that two ligand molecules interact with one cation (Fig. 1c). The enthalpies of interaction with Cu^{2+} are too small to allow any firm conclusions concerning the stoichiometry to be drawn.

It should be noted that the change in ionic strength on going from a 0.05 to a 0.15 mol.dm^{-3} salt solution may affect the stability constants of the metal ion–glycoside complexes and thus the shape of the curves in Fig. 1. Moreover, the interaction of the anions of the salts employed with the complexed metal ion may also

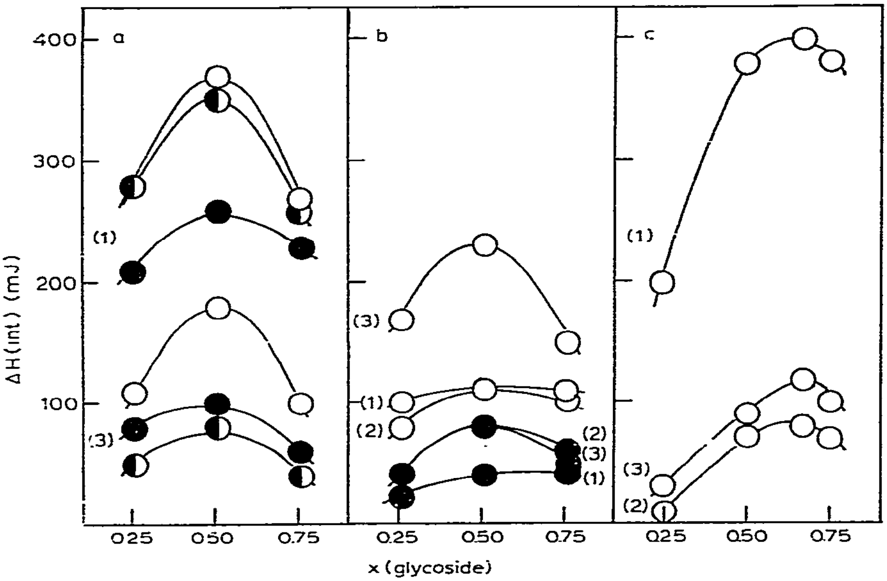

Fig. 1. Enthalpies of interaction [ΔH(int.)] of methyl α-D-ribo- (1), β-D-ribo- (2), and α-D-lyxofuranosides (3) with various metal ions plotted against the proportion of the glycoside [x(glycoside)] in the mixtures: (a) $CaCl_2$ (—○—), $SrCl_2$ (—●—), and $BaCl_2$ (—◐—); (b) $La(NO_3)_3$ (—○—) and $Y(NO_3)_3$ (—●—); (c) $Pb(NO_3)_2$.

contribute to the observed enthalpies of interaction. For example, the ΔH(int.) values obtained with calcium nitrate are ~40 mJ more negative than those with calcium chloride. However, we believe that the suggested difference in the stoichiometry of the lead(II) complexes compared to that of the other complexes is real. A possible explanation for this difference is that the complexes of Pb^{2+} (a relatively soft ion) exhibit a considerable degree of covalency, whereas the cations with a noble-gas structure interact with the ligands almost entirely electrostatically.

The calorimetric data presented above also support earlier suggestions concerning the stabilities of various metal ion–carbohydrate complexes[4,10,13,16]. The enthalpies of interaction of Mg^{2+} with the methyl glycofuranosides are almost negligible, in accord with the proposed instability of its polyol complexes[4]. The other alkaline-earth metal cations exhibit stronger interactions with methyl α-D-riboside than with methyl α-D-lyxoside and methyl β-D-riboside; with each ligand, calcium possesses the greatest tendency for complex-formation. The enthalpy values measured for Pb^{2+} behave similarly and agree with the observation that the lead(II) complexes of free monosaccharides having five-membered rings are approximately of the same stability as the calcium complexes[10]. However, with yttrium(III) and lanthanum(III), the interactions with methyl α-D-lyxoside show the most negative enthalpies, most probably reflecting the greatest stability among the complexes. Possible reasons for this change in the complexing order of the ligands have been discussed[16]. The low ΔH(int.) values obtained with Cu^{2+} suggest that the 3d transition-metal ions do not markedly interact with carbohydrates in aqueous solution. The small size of these ions compared to Ca^{2+}, La^{3+}, and Pb^{2+} offers a possible explanation for the low complexing-ability. It should be noted that ^{1}H-n.m.r. data suggest[4] a considerable destabilisation of the complexes on going from Na^{+} to Li^{+}, from Ca^{2+} to Mg^{2+}, from Pb^{2+} to Sn^{2+}, and from Cd^{2+} to Zn^{2+}, *i.e.*, as the ionic radius becomes markedly smaller than 1 Å.

EXPERIMENTAL

Materials. — The methyl glycofuranosides were synthesised as described earlier[17,18]. The inorganic salts employed were of analytical grade. Their solutions were made in distilled and degassed water.

Calorimetric measurements. — An LKB 10700-2 Batch Microcalorimeter at 298.2 K was used, as described earlier[14].

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